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Small Modular Reactors: The Army's Secure Source of Energy?

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SMALL MODULAR REACTORS: THE ARMY'S SECURE SOURCE OF ENERGY?

by

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ABSTRACT

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The purpose of this paper is to evaluate the current state of the electric energy grid, the factors that influence its reliability, and identify the Department of Defense (DoD) requirements for secure energy sources at critical military facilities. This paper outlines the history of small modular reactors (SMR) relative to the DoD, the current state of SMR design, development, safety, and describes the need for DoD to pursue this technology as a viable source of secure energy in the future.

SMRS: THE ARMY'S SECURE SOURCE OF ENERGY?

> Some folks want wind and solar. Others want nuclear, clean coal and natural gas. To meet this goal, we will need them all.
>
> —Barrack Obama
> State of the Union
> January 25, 2011

In recent years, the U.S Department of Defense (DoD) has identified a security issue at our installations related to the dependence on the civilian electrical grid.[1] The DoD depends on a steady source of electricity at military facilities to perform the functions that secure our nation. The flow of electricity into military facilities is controlled by a public grid system that is susceptible to being compromised because of the age of the infrastructure, damage from natural disasters and the potential for cyber attacks. Although most major functions at military installations employ diesel powered generators as temporary backup, the public grid may not be available to provide electricity when it is needed the most. The United States electrical infrastructure system is prone to failures and susceptible to terrorist attacks.[2] It is critical that the source of electricity for our installations is reliable and secure. In order to ensure that our military facilities possess a secure source of electricity, either the public system of electric generation and distribution is upgraded to increase its reliability as well as reducing its susceptibility to cyber attack or another source of electricity should be pursued. Although significant investments are being made to upgrade the electric grid, the current investment levels are not keeping up with the aging system.

Small modular reactors (SMRs) are nuclear reactors that are about an order of magnitude smaller than traditional commercial reactor used in the United States. SMRs are capable of generating electricity and at the same time, they are not a significant contributor to global warming because of green house gas emissions. The DoD needs to look at small modular nuclear reactors (SMRs) to determine if they can provide a safe and secure source of electricity.

Electrical Grid Susceptibility to Disruptions

According to a recent report by the Defense Science Board, the DoD gets ninety nine percent of their electrical requirements from the civilian electric grid.[3] The electric grid, as it is currently configured and envisioned to operate for the foreseeable future, may not be reliable enough to ensure an uninterrupted flow of electricity for our critical military facilities given the influences of the aging infrastructure, its susceptibility to severe weather events, and the potential for cyber attacks. The DoD dependency on the grid is reflected in the $4.01 Billion spent on facilities energy in fiscal year 2010, the latest year which data was available.[4] The electricity used by military installations amounts to $3.76 billion.[5] As stated earlier, the DoD relies on the commercial grid to provide a secure source of energy to support the operations that ensure the security of our nation and it may not be available when we need it. The system could be taken down for extended periods of time by failure of aging components, acts of nature, or intentionally by cyber attacks.

Aging Infrastructure. The U.S electric power grid is made up of independently owned power plants and transmission lines. The political and environmental resistance to building new electric generating power plants combined with the rise in consumption and aging infrastructure increases the potential for grid failure in the future. There are components in the U.S. electric grid that are over one hundred years old and some of the recent outages such as the 2006 New York blackout can be directly attributed to this out of date, aging infrastructure.[6] Many of the components of this system are at or exceeding their operational life and the general trend of the utility companies is to not replace power lines and other equipment until they fail.[7] The government led deregulation of the electric utility industry that started in the mid 1970s has contributed to a three decade long deterioration of the electric grid and an increased state of instability. Although significant investments are being made to upgrade the electric grid, the many years of prior neglect will require a considerable amount of time and funding to bring the aging infrastructure up to date. Furthermore, the current investment levels to upgrade the grid are not keeping up with the aging system.[8] In addition, upgrades to the digital infrastructure which were done to increase the systems efficiency and reliability, have actually made the system more susceptible to cyber attacks.[9] Because of the aging infrastructure and the impacts related to weather, the extent, as well as frequency of failures is expected to increase in the future.

Adverse Weather. According to a 2008 grid reliability report by the Edison Electric Institute, sixty seven per cent of all power outages are related to weather. Specifically, lightning contributed six percent, while adverse weather provided thirty one percent and vegetation thirty percent (which was predominantly attributed to wind blowing vegetation into contact with utility lines) of the power outages.[10] In 1998 a falling tree limb damaged a transformer near the Bonneville Dam in Oregon, causing a cascade of related black-outs across eight western states.[11] In August of 2003 the lights went out in the biggest blackout in North America, plunging over fifty million people into darkness over eight states and two Canadian provinces. Most areas did not have power restored four or five days. In addition, drinking water had to be distributed by the National Guard when water pumping stations and/or purification processes failed. The estimated economic losses associated with this incident were about five billion dollars. Furthermore, this incident also affected the operations of twenty two nuclear plants in the United States and Canada.[12] In 2008, Hurricane Ike caused approximately seven and a half million customers to lose power in the United States from Texas to New York.[13] The electric grid suffered numerous power outages every year throughout the United States and the number of outages is expected to increase as the infrastructure ages without sufficient upgrades and weather-related impacts continue to become more frequent.

Cyber Attacks. The civilian grid is made up of three unique electric networks which cover the East, West and Texas with approximately one hundred eighty seven thousand miles of power lines. There are several weaknesses in the electrical distribution infrastructure system that could compromise the flow of electricity to military facilities. The flow of energy in the network lines as well as the main distribution hubs has become totally dependent on computers and internet-based communications. Although the digital infrastructure makes the grid more efficient, it also makes it more susceptible to cyber attacks. Admiral Mr. Dennis C. Blair (ret.), the former Director of National Intelligence, testified before Congress that "the growing connectivity between information systems, the Internet, and other infrastructures creates opportunities for attackers to disrupt telecommunications, electrical power, energy pipelines, refineries, financial networks, and other critical infrastructures.[14]"

The Intelligence Community assesses that a number of nations already have the technical capability to conduct such attacks.[15] In the 2009 report, *Annual Threat Assessment of the Intelligence Community for the Senate Armed Services Committee,* Adm. Blair stated that “Threats to cyberspace pose one of the most serious economic and national security challenges of the 21st Century for the United States and our allies.”[16] In addition, the report highlights a growing array of state and non-state actors that are targeting the U.S. critical infrastructure for the purpose of creating chaos that will subsequently produce detrimental effects on citizens, commerce, and government operations. These actors have the ability to compromise, steal, change, or completely destroy information through their detrimental activities on the internet.[17] In January 2008, US Central Intelligence Agency senior analyst Tom Donahue told a gathering of three hundred international security managers from electric, water, oil & gas, and other critical industry, that data was available from multiple regions outside the United States, which documents cyber intrusions into utilities. In at least one case (outside the U.S.), the disruption caused a power outage affecting multiple cities. Mr. Donahue did not specify who executed these attacks or why, but did state that all the intrusions were conducted via the Internet.[18]

During the past twenty years, advances in computer technologies have permeated and advanced all aspects of our lives. Although the digital infrastructure is being increasingly merged with the power grid to make it more efficient and reliable, it also makes it more vulnerable to cyber attack. In October 2006, a foreign hacker invaded the Harrisburg, PA., water filtration system and planted malware.[19] In June 2008, the Hatch nuclear power plant in Georgia shut down for two days after an engineer loaded a software update for a business network that also rebooted the plant's power control system. In April 2009, *The Wall Street Journal* reported that cyber spies had infiltrated the U.S. electric grid and left behind software that could be used to disrupt the system. The hackers came from China, Russia and other nations and were on a “fishing expedition” to map out the system. [20] According to the secretary of Homeland Security, Janet Napolitano at an event on 28 October 2011, cyber–attacks have come close to compromising the country’s critical infrastructure on multiple occasions.[21] Furthermore, during FY11, the United States Computer Emergency Readiness Team took action on more than one hundred thousand incident reports by releasing more than five thousand actionable cyber security alerts and information products.[22]

The interdependence of modern infrastructures and digital based systems makes any cyber attacks on the U.S. electric grid potentially significant. The December 2008 report by the Commission on Cyber Security for the forty fourth Presidency states the challenge plainly: “America’s failure to protect cyberspace is one of the most urgent national security problems facing the new administration”.[23] The susceptibility of the grid to being compromised has resulted in a significant amount of resources being allocated to ensuring the systems security. Although a substantial amount of resources are dedicated to protecting the nation’s infrastructure, it may not be enough to ensure the continuous flow of electricity to our critical military facilities. SMRs as they are currently envisioned may be able to provide a secure and independent alternative source of electricity in the event that the public grid is compromised. SMRs may also provide additional DoD benefit by supporting the recent government initiatives related to energy consumption and by circumventing the adverse ramifications associated with building coal or natural gas fired power plants on the environment.

Addressing the DoD Requirement for Secure Energy Resources

The use of SMRs as an alternative energy source by the DoD could help it to meet several sustainable energy initiatives as well as significantly reduce the generation of green house gases, reduce dependence on fossil fuels, and at the same time provide a secure source of independently generated electricity. In 2010 the Secretary of Defense, Robert M. Gates identified energy as one of the top twenty five transformational priorities for the DoD.[24] The 2010 Quadrennial Defense Review specifically addressed energy for the first time as a strategic issue. In particular, the DoD stated that it would collaborate with other federal agencies to research, develop, test, and evaluate (RDT&E) innovative sustainable energy technologies. [25]

The Energy Independence and Security Act of 2007 (EISA 2007) signed on December 19, 2007 by President Bush, reinforces the energy goals set forth in Executive Order (E.O.) 13423 and according to the Environmental Protection Agency, specifically aims to:

- Move the U.S. toward greater energy independence and security;
- Increase the production of clean renewable fuels;
- Protect consumers;
- Increase the efficiency of products, buildings, and vehicles;
- Promote research on and deploy greenhouse gas capture and storage options;
- Improve the energy performance of the Federal Government; and
- Increase U.S. energy security, develop renewable fuel production, and improve vehicle fuel economy.[26]

E.O. 13514, “Federal Leadership in Environmental, Energy, and Economic Performance,” expands on the energy reduction and environmental performance requirements identified in E.O. 13423 for Federal agencies. E.O. 13514 specifically requires that cost effective, innovative approaches be identified and implemented to reduce the consumption of electricity. In addition, it also states that the Federal Government will reduce greenhouse gas emissions twenty eight percent by 2020.[27] Nuclear power plants emit very little greenhouse gases in conjunction with their daily operations as well as over the lifecycle of the plant. SMRs would help significantly with meeting the E.O. 13514 greenhouse gas emission goal and may provide a secure alternative source of electricity for critical military operations.

Section 332 of the FY2010 National Defense Authorization Act (NDAA), “Extension and Expansion of Reporting Requirements Regarding Department of Defense Energy Efficiency Programs,” requires the Secretary of Defense to evaluate the cost and feasibility of a policy that would require new power generation projects established on installations to be able to provide power for military operations in the event of a commercial grid outage.[28] A potential solution to meet this national security requirement, as well as the critical needs of nearby towns, is for DoD to evaluate SMRs as a possible source for safe and secure electricity. Military facilities depend on reliable sources of energy to operate, train, and support national security missions. The power demand for most military facilities is not very high, and could easily be met by a SMR. Table 1 provides the itemized description of the annual energy requirements in megawatt of electricity (MWe) required for the three hundred seventy four DoD installations.[29]

Plant Size	Number of DoD Installations
10 MWe or less	170
10-20 MWe	84
20-30 MWe	50
30-133 MWe	70

Table 1: Energy Requirements for DoD Installations

DoD History with SMRs

The concept of small reactors for electrical power generation is not new. In fact, the DoD built and operated small reactors for applications on land and at sea. The U.S. Army operated eight nuclear power plants from 1954 to 1977. Six out of the eight reactors built by the Army produced operationally useful power for an extended period, including the first nuclear reactor to be connected and provide electricity to the commercial grid. [30] The Army program that built and operated compact nuclear reactors was ended after 1966, not because of any safety issues, but strictly as a result of funding cuts in military long range research and development programs. In essence, it was determined that the program costs could only be justified if there was a unique DoD specific requirement. At the time there were none.[31] Although it has been many years since these Army reactors were operational, the independent source of energy they provided at the time is exactly what is needed again to serve as a secure source of energy today. Many of the nuclear power plant designs used by the Army were based on United States Naval reactors. Although the Army stopped developing SMRs, the Navy as well as the private sector has continued to research, develop, and implement improved designs to improve the safety and efficiency of these alternative energy sources.

The U.S. Navy nuclear program developed twenty seven different power plant systems and almost all of them have been based on a light water reactor design.[32] This design focus can be attributed to the inherent safety and the ability of this design to handle the pitch and roll climate expected on a ship at sea. To date, the U. S Navy operated five hundred twenty six reactor cores in two hundred nineteen nuclear powered ships, accumulated the equivalent of over six thousand two hundred reactor years of operation and safely steamed one hundred forty nine million miles. The U.S. Navy has never experienced a reactor accident.[33] All of the modern Navy reactors are design to use fuel that is enriched to ninety three percent Uranium 235 (U_{235}) versus the approximate three percent U_{235} used in commercial light water reactors. The use of highly enriched U_{235} in Navy vessels has two primary benefits, long core lives and small reactor cores.[34] The power generation capability for naval reactors ranges from two hundred MWe (megawatts of electricity) for submarines to five hundred MWe for an aircraft carrier. A Naval reactor can expect to operate for at least ten years before refueling and the core has a fifty year operational life for a carrier or thirty to forty years for a submarine.[35] As an example, the world’s first nuclear carrier, the USS Enterprise, which is still operating, celebrated fifty years of operations in 2011.[36] The Navy nuclear program has set a precedent for safely harnessing the energy associated with the nuclear fission reaction. In addition, the Navy collaborates with the private sector to build their reactors and then uses government trained personnel to serve as operators.

Implementing the use of SMRs as a secure source of energy for our critical military facilities will leverage this knowledge and experience.

Light Water Reactor Design

All of the operational reactors used by the DoD have been based on the light water reactor design. This is the same basic design although significantly scaled up, by one to two orders of magnitude, in terms of size and output that has been used commercially in the continental United States to produce electricity. The nuclear fission reactors used in the United States for electric power production are also classified as "light water reactors". Light water (ordinary water) is used as the moderator in these reactors as well as the cooling agent and the means by which heat is removed to produce steam for turning the turbines of the electric generators. The two varieties of light water reactors currently used in U.S. commercial electric power production are the pressurized water reactor and boiling water reactor.[37]

The pressurized water reactor is the most common type used for generating U.S. commercial electricity and also as a source of power for Navy vessels. A schematic of the general design is shown in figure one.[38] The water used in this type of reactor core is regular water maintained under pressure so that when the nuclear reaction heats it up, the water does not boil and the heat is transferred to a separate water system to generate steam to turn a turbine which then produces electricity. In the second type of light water reactors, the boiling water reactor, the steam generated in the nuclear reaction, boils the ordinary water which is then used directly to turn the turbine and generate electricity. A schematic of the general design is shown in figure two.[39]

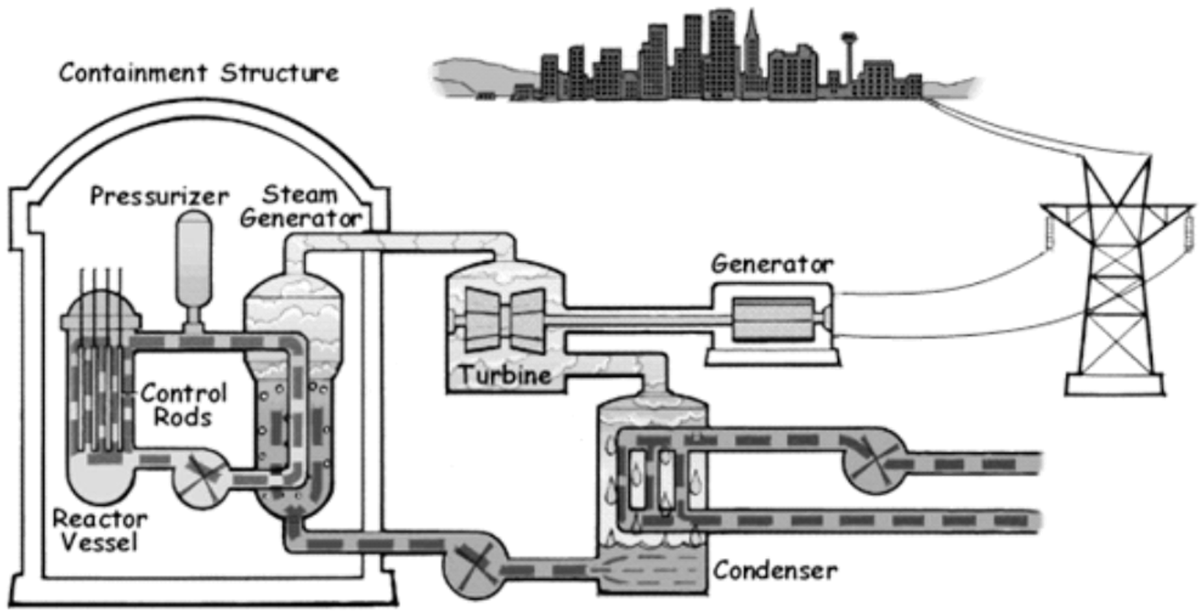

Figure1: Pressurized Water Reactor Schematic

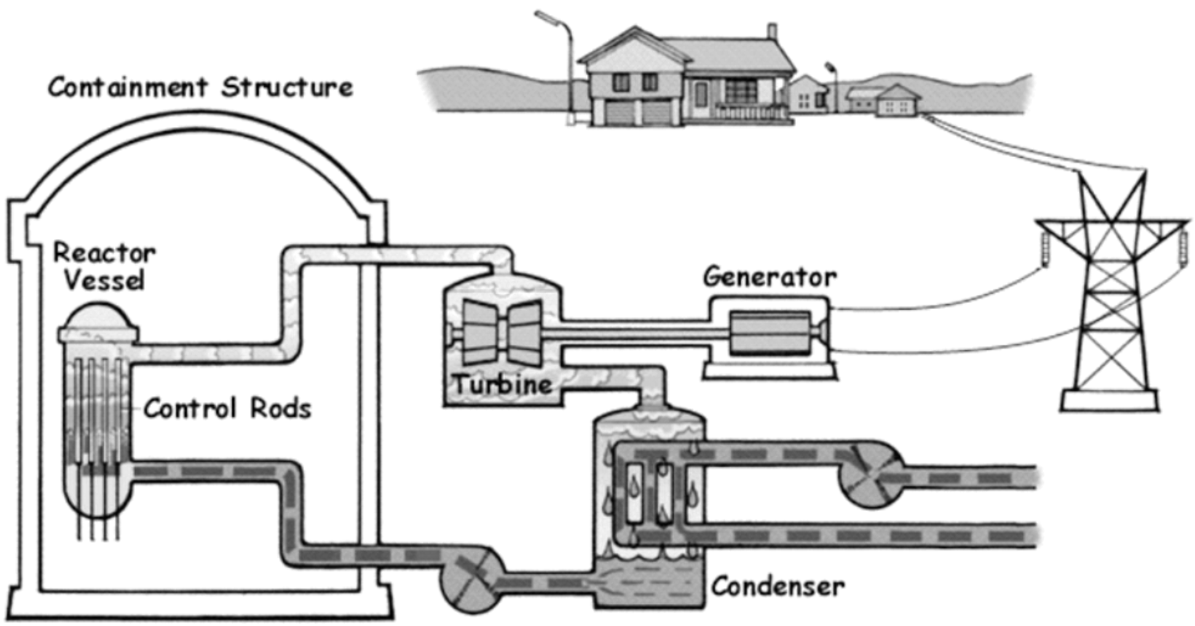

Figure 2: Boiling Water Reactor Schematic

After flowing through the turbine, the steam condenses into water in the condenser and is re-circulated. The water required to cool the condenser can be taken from a river or the heat can be dissipated using a cooling tower. There is a third type of light water reactor which is referred to as a supercritical water reactor. Although this final type reactor is considered to be significantly more efficient than the other two, it is currently just a theoretical design. None have been built for commercial applications.

Nuclear Power Development

The initial use of nuclear fuel as a source of electrical power generation created prototypes and initial power plants designs that did not incorporate safety features and procedures that are prevalent in currently operating power plants. The development of nuclear power plant technology to date has evolved as four distinct design generations:[40]

- First Generation: prototypes, and first initial operating plants (~1950-1970)
- Second Generation: current operating plants (~1970-2030)
- Third Generation: deployable improvements to current reactors (~2000 and on).
- Fourth Generation: theoretically advanced and new reactor systems (2030 and beyond)

Some of these changes are due to improvements in the state-of-the-art, while others are the result of lessons learned following incidents and the subsequent increase in regulatory guidance. Each subsequent series of designs has resulted in enhancements that increase the sustainability, reliability, safety, and economics associated with the use of nuclear fuel for electrical power production.[41] The development and implementation of light water SMRs would represent the generation III phase and would incorporate many of the targeted goals being pursued by the Generation IV International Forum (GIF).[42] The GIF is a collaborative effort of the world's leading nuclear technology nations to develop a next generation of innovative nuclear technologies to meet the world's energy requirements.[43] The SMRs currently proposed for applications in the U.S. will incorporate many of the GIF goals, including fuel cycle sustainability, enhanced reliability, safety, and improved economics.[44]

SMR Development

For the purposes of this paper, the SMRs will be restricted to two categories. The first category will build on the extensive working knowledge and regulatory review associated with light water reactors. The second category represents the innovative designs that are being developed and will need to complete the regulatory approval process. The light water reactor has the lowest technological risk, because of its similarity to commercially operated power plants and the naval reactor designs being used today. They can use fuel enriched to less than 5% U_{235} compared to Navy reactors and may have an extended refueling interval. The regulatory hurdles associated with the light water reactors are expected to be the least of any SMRs currently being proposed. Theoretically, these should have a significantly shorter processing time for fielding since their inherent features are so similar to existing reactors.[45] Three proposed pressurized light water reactors are depicted in Figure three,[46] with their electrical power output. The estimated time to fielding is ten years.[47]

The second category incorporates several of the more advanced innovative reactor technologies that promise to be more efficient, easier to operate, safer, and less costly. These designs are commonly referred to as Generation IV and some examples are provided in Figure four.[48] The Generation IV advanced innovative designs use different forms of coolant such as helium, sodium or lead-bismuth. These innovative reactor designs will take longer to field because of the additional time required for the proof of concept and the regulatory process versus the pressurized light water reactors, but should be deployable by 2030. They also exhibit the potential to expand the utility of nuclear energy to the fields of hydrogen or synthetic hydrocarbon production, sea water desalination and process heat production.[49]

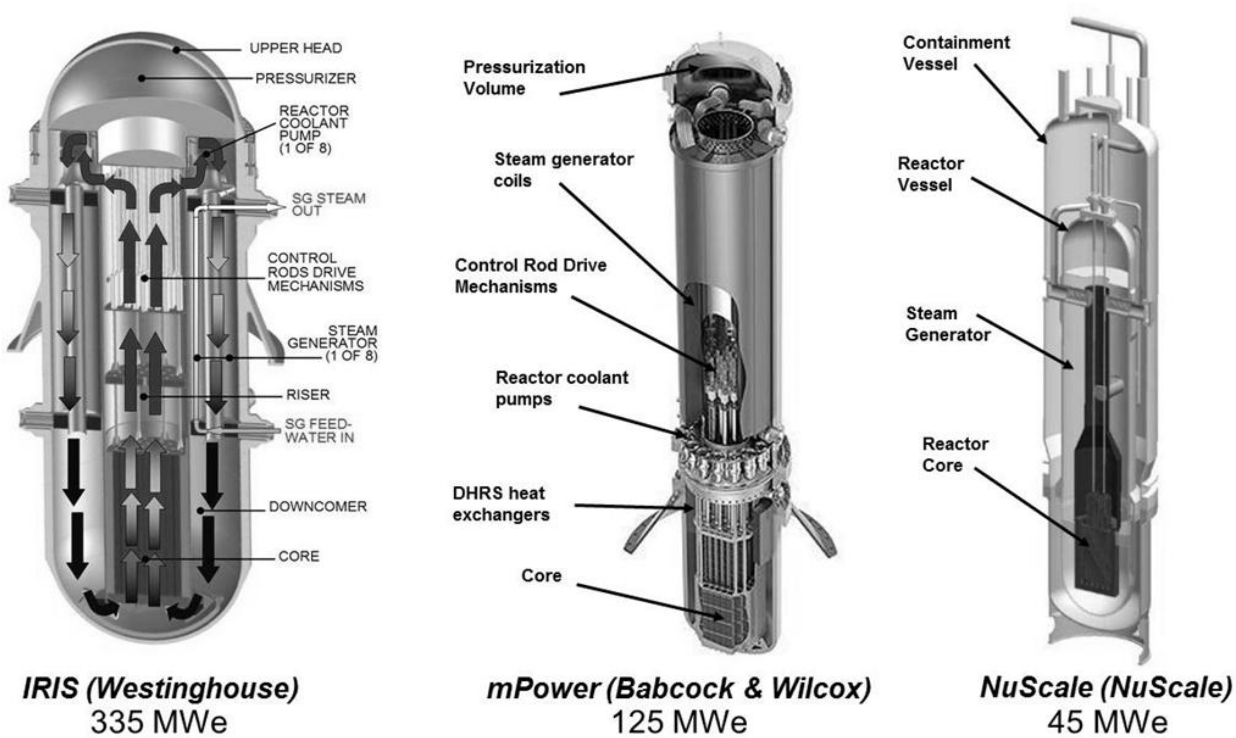

Figure 3: Proposed Small Modular Pressurized Water Reactors

<u>SMR Advantages</u>

There are several features associated with the proposed SMRs that may make them attractive as alternative sources for electric power generation. Most of the currently proposed SMR designs plan to have the core and other major components manufactured in a factory type environment and then shipped to the site.[50] This process should reduce capital costs; provide a consistent high level of quality, improve safety and save time during the implementation phase. One of the advantages of the modular design is the fact that these reactors can be operated as independent modules where electrical requirements are low or remotely located. In locations where the demand for electricity is higher, they can be combined to form a larger compound of modules.

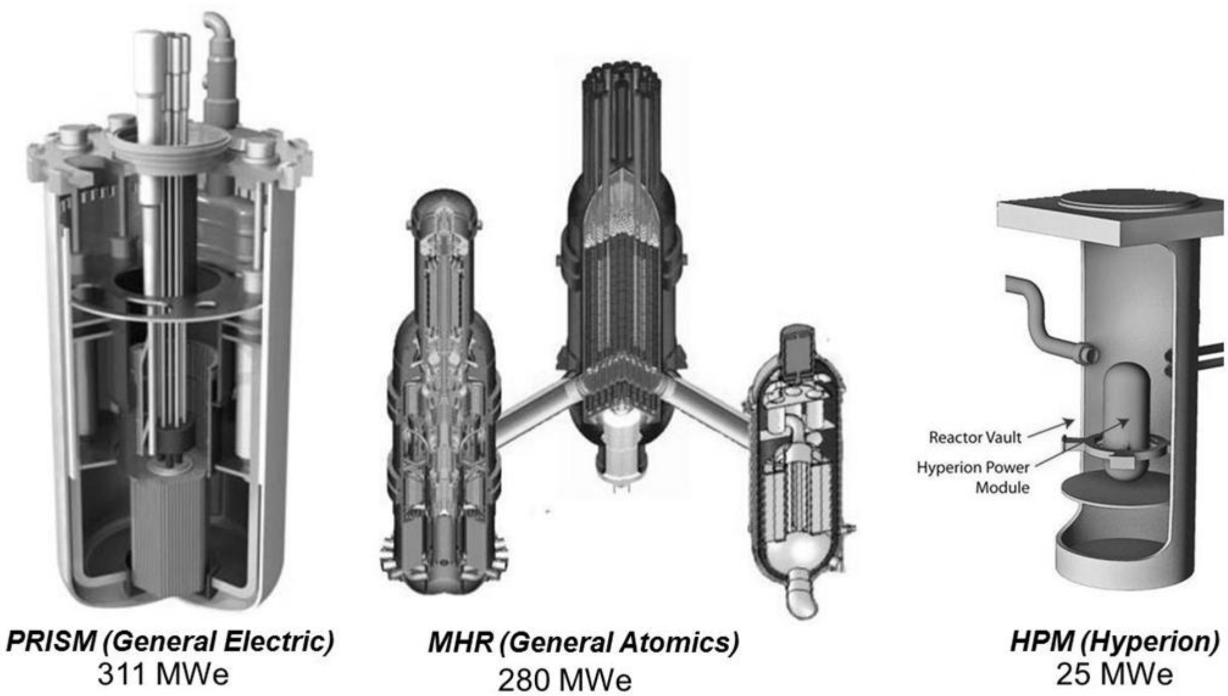

Figure 4: Models of Three Advanced Innovative Reactor Designs

These larger groups of collocated modules will create an economy of scale and make the system costs to operate similar to or less than the commercial plants with a similar output. Additional cost savings may be realized in the SMR designs with extended refueling intervals.

Many of the Generation IV designs utilize innovative concepts that also may extend the life of the reactor core and therefore reduce the lifecycle costs. Although these concepts will require additional testing and regulatory acceptance, they are expected to reduce overall costs and extend the time required between refueling. Even the proposed SMRs that mimic the light water reactor design used by the commercial sector are expected to operate for forty two to forty eight months versus the eighteen to twenty four month refueling interval for commercial plants. In addition, one of the significant advantages of SMRs is the minimal amount of carbon dioxide (greenhouse gases) that is released in conjunction with the lifecycle operations. This benefit will help DoD attain some of its energy sustainability goals. These advantages will be confirmed as the initial prototypes are constructed and evaluated. In addition, these prototypes will also provide an opportunity to confirm the safety features that are incorporated in the proposed SMR designs.

SMR Safety

Although the SMRs proposed for land based applications are still in the early stages of their design, the small modular scale may provide several potential safety features such as longer refueling cycles, passive cooling, and subsurface containment vessels for increased security. Some of the proposed modern modular reactors incorporate passive cooling as a safety feature associated with their smaller, lower power and simpler design.[51] Passive cooling will use the natural circulation of the primary coolant to remove heat, as opposed to the requirement for supplemental and redundant pumping systems, piping and other components that are required to keep the reactors from overheating. Finally, several of the proposed SMR designs are small enough that they may be able to be buried in the ground and thereby provide an additional layer of physical protection and security from terrorist attacks.[52]

Current-generation safety-related systems	**SMR safety systems**
High-pressure injection system. Low-pressure injection system.	No active safety injection system required. Core cooling is maintained using passive systems.
Emergency sump and associated net positive suction head (NPSH) requirements for safety-related pumps.	Passive cooling does not need safety-related pumps for accident mitigation; therefore, no need for sumps and protection of their suction supply.
Emergency diesel generators.	Passive design does not require emergency alternating-current (ac) power to maintain core cooling. Core heat removed by heat transfer through vessel.
Active containment heat systems.	None required because of passive heat rejection out of containment.
Containment spray system.	Spray systems are not required to reduce steam pressure or to remove radioiodine from containment.
Emergency core cooling system (ECCS) initiation, instrumentation and control (I&C) systems. Complex systems require significant amount of online testing that contributes to plant unreliability and challenges of safety systems with inadvertent initiations.	Simpler and/or passive safety systems require less testing and are not as prone to inadvertent initiation.
Emergency feed water system, condensate storage tanks, and associated emergency cooling water supplies.	Ability to remove core heat without an emergency feed water system is a significant safety enhancement.

Table 2: Current-Generation Plant Safety Systems versus Potential SMR Design

In 2010, the American Nuclear Society, a professional organization of scientists and engineers devoted to the peaceful application of nuclear science, generated a draft report which documented (see Table two) current-generation nuclear plant safety systems versus potential SMR designs.[53]

The primary nuclear power concerns of the public are nicely captured by Richard A. Muller in his book *Physics for Future Presidents: the Science behind the Headlines.* Mr. Muller states that in the late twentieth century, after the Three Mile Island nuclear reactor accident, a moratorium on nuclear power prevented the construction of new plants because it was perceived that they were unsafe. The key dangers people identified at the time were 1) the fear of a catastrophic accident and a subsequent meltdown of the nuclear core 2) the plutonium generated in a reactor can be diverted to build bombs and 3) the potential environmental and toxicological effects of the nuclear waste.[54]

To date, there has never been a complete meltdown of a nuclear reactor in the United States. The accident at Three Mile Island, which served as a catalyst for starting the moratorium, did have a partial meltdown due to a loss of coolant, but was suppressed as designed by the steel containment vessel.[55] Based on 1979 Kemeny Commission and the Environmental Protection Agency report, there was no addition risk of cancer associated with this accident.[56] The second issue identified as a concern by the public, is the fear of a "plutonium economy", where the plutonium wastes could be used to manufacture a bomb. This fear has not materialized because there are no commercial breeder reactors allowed to operate in the United States.[57] The third issue identified as a concern to the public is the risk associated with the storage of the nuclear waste. The current method of storing the material in pools at the reactor site is an acceptable storage solution at this time, but an approved long term storage facility or recycling program is a better solution for the foreseeable future.

The nuclear waste storage facility at Yucca Mountain, Nevada was constructed solely for this purpose. Unfortunately, this facility has not been approved to date, even though it can be shown to have a very low operational risk according to calculations by Dr. Richard A Muller in his book “Physics for Future Presidents”. Dr. Muller makes a very good argument using physics based math calculations, that the nuclear waste encapsulated in glass and stored in Yucca Mountain is the safest storage alternative available. The risk associated with this option can be shown to be less than the risk of radiation exposure associated with the original uranium if it had been left in the ground.[58] The calculations take into account the radioactivity of the waste materials, their respective half lives, the dose rate expected to increase the risk of cancer, the probability of this material escaping from the glass capsules into the groundwater and the amount that would have to leak to be a safety risk. The final conclusion of these calculations and assumptions is that the danger associated with the natural uranium in the Colorado Mountains is greater by a factor of twenty times the legal limit of the material stored at Yucca Mountain.[59] The risk associated with storage in Yucca Mountain can be shown to last up to three hundred years (assumes one hundred percent probability that one percent of the waste will leak out into the environment), while the naturally occurring uranium will be hazardous for more than thirteen billion years.[60] In summary, nuclear waste storage is perceived as a hazard and the statistical probability of a release or the ensuing environmental and toxicological ramifications must be understood and accepted by the public as part of any future energy planning strategy.

A consideration for handling nuclear waste is to recycle the material and reuse it in nuclear power plants as a fuel instead of handling it as a waste. This is not a new concept. Nuclear waste was recycled in the U.S. until 1976 when the program was canceled by President Carter due to a fear of nuclear weapons proliferation. The ban was lifted by President Reagan, but no government funding was provided to restart the recycling program.[61] The nuclear waste can be recycled so that ninety six percent of the material is reused. France, India, Russia and the United Kingdom recycle their nuclear waste.[62] The U.S. needs to reevaluate the nuclear waste recycling program.

Another area of safety that has to be addressed is the physical protection of the facilities themselves. To date this has not been an issue, but power generation facilities may be at risk of terrorist attacks because they are viewed as a high value target. SMRs, because of their small signature, have several options available that can mitigate this risk. The proposed NuScale SMR design incorporates reactors housed in high strength stainless steel vessels, encased in pools of water below the ground surface to mitigate seismic effects, and inside buildings built to withstand the effects of hurricanes, tsunamis and airborne terrorist attacks.[63] Other proposed designs incorporate similar or alternative options to ensure the safety of the reactor in the event of a terrorist attack. As the designs and prototypes mature, a clearer vision for their future implementation will be realized. The bottom line is that these improved reactor designs are building on past experiences, incorporating the most advanced safety features, and may be more efficient than any reactors that have preceded them.

Conclusion

There is a definite national security issue associated with our military installations and their dependence on the civilian electrical grid which is susceptible to being compromised. The DoD must mitigate this vulnerability and develop a safe and secure source of energy as soon as possible. The security of our great nation may depend on how quickly this issue is resolved. Efforts are underway to bring the aging electric grid infrastructure up to date. Furthermore, a significant amount of resources has been approved to help ensure the reliability of the electric grid as well as the security of the grids digital infrastructure from cyber attacks. Improvements to the electric grid are one option to address this issue, but we must also look at alternative sources of independent energy. It is critical that the source of electricity for our critical military installations is reliable and secure to ensure the security of our nation. The DoD needs to consider small modular nuclear reactors as a safe and secure alternative source of electricity. In addition, DoD needs to pursue all available partnering and funding options to ensure the safe and timely implementation of SMRs at appropriate military facilities.

Endnotes

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SM-1: 2 MWe: Fort Belvoir, VA, Initial criticality April 8, 1957 and the first U.S. nuclear power plant to be connected to an electrical grid. Used primarily for training and testing, rather than power generation for Ft. Belvoir.

SL-1: 300kWe: National Reactor Testing Station, Idaho. Initial criticality August 11, 1958. The SL-1 was designed by the Argonne National Laboratory to gain experience in boiling water reactor operations, develop performance characteristics, train military crews, and test components.

PM-2A: 2 MWe, plus heating. Camp Century, Greenland. Initial criticality October 3, 1960. The first "portable" nuclear power reactor. Brought to Greenland in parts, assembled, operated, disassembled, and shipped back to United States. This reactor was designed and built to demonstrate the ability to assemble a nuclear power plant from prefabricated components in a remote, arctic location. The pressure vessel was subsequently used to investigate neutron embrittlement in carbon steel.

ML-1: Designed for 300 kWe, but only achieved 140 kWe, first closed cycle gas turbine. Initial criticality was on March 30, 1961. Operated for only a few hundred hours of testing. The ML-1 was designed to test an integrated reactor package that was transportable by military semi-trailers, railroad flatcars, and barges.

PM-1: 1.25 MWe, plus heating. Sundance, Wyoming. Initial criticality was on February 25, 1962. This pressurized water reactor was used to provide electric power to the 731st Radar Squadron of the North American Air Defense Command (NORAD).

PM-3A: 1.75 MWe, plus heating and desalinization. McMurdo Station, Antarctica. Initial criticality March 3, 1962, designed to provide electric power and steam heating to the Naval Air Facility at McMurdo Sound.

SM-1A: 2 MWe, plus heating. Fort Greely, Alaska. Initial criticality March 13, 1962, designed as the first field facility developed under the Army Nuclear Power Program. This site was selected to develop construction methods in a remote, arctic location.

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Sustainability-1 Generation IV nuclear energy systems will provide sustainable energy generation that meets clean air objectives and provides long-term availability of systems and effective fuel utilization for worldwide energy production.

Sustainability-2 Generation IV nuclear energy systems will minimize and manage their nuclear waste and notably reduce the long-term stewardship burden, thereby improving protection for the public health and the environment.

Economics-1 Generation IV nuclear energy systems will have a clear life-cycle cost advantage over other energy sources.

Economics-2 Generation IV nuclear energy systems will have a level of financial risk comparable to other energy projects.

Safety and Reliability-1 Generation IV nuclear energy systems operations will excel in safety and reliability.

Safety and Reliability-2 Generation IV nuclear systems will have a very low likelihood and degree of reactor core damage.

Safety and Reliability-3 Generation IV nuclear energy systems will eliminate the need for offsite emergency response.

Proliferation resistance and Physical Protection Generation IV nuclear energy systems will increase the assurance that they are very unattractive and the least desirable route for diversion or theft of weapons-usable materials, and provide increased physical protection against acts *of* terrorism.

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